3.2 AIRCRAFT MOVEMENT

Brawler uses several different methods of commanding an aircraft to change its current flight status, but the one used for short term, close combat maneuvers requests a new velocity vector and the number of g's that can be pulled to achieve it. To accomplish the specified change in aircraft flight path, the angle between the current and new velocity vector is translated into desired pitch and roll rates which will stabilize the aircraft at the new orientation angle in the shortest possible time. Section 2.2.1 and Appendix C of reference (a) describe in detail the derivation of the equations which bring about this transformation. If the aircraft Z axis is oriented with the desired maneuver plane, so roll motion is not required, then the desired change in pitch rate Ψ^* is given by:

$$\Psi^* = (\delta^2\tau)/2\ (\theta^*-\theta) - (\delta\tau-1)\Psi \qquad [3.2\text{-}1]$$

Where:
- Ψ^* is the desired rate
- Ψ is the current pitch rate
- τ is an aircraft specific time constant
- δ is a frequency term

Thus, the desired change in rate is dependent on the angular difference between the new and old velocity vectors ($\theta^*-\theta$) and the current pitch rate Ψ. A similar equation exists for the desired roll rate. These equations are then related through the aircraft roll angle so that the magnitude of the pitch maneuver will increase to the desired value as the roll angle approaches zero. Multiplying the desired pitch rate by the aircraft velocity produces a desired transverse acceleration A*. Desired pitch rate in the current maneuver plane is reduced by the cosine of the roll angle, such that;

$$A^* \cos\varphi = \Psi^* V_{a/c} \qquad \text{or} \qquad (\Psi^*) = (A^* \cos\varphi) / V_{a/c} \qquad [3.2\text{-}2]$$

Where:
- A^* is the desired transverse acceleration in the desired maneuver plane
- $V_{a/c}$ is the aircraft velocity
- φ is the roll angle between the current and desired maneuver planes

Having established the new flight parameters the aircraft would like to achieve and the angular velocities to be used in making the change, the response of an aircraft depends on its aerodynamic coefficients and control equations. Brawler provides two options (aerodynamic algorithms) for representing aircraft response. Option 1 is reported to be the standard model while option 2 allows the user much more latitude to model new design features, such as digital control systems or roll and pitch augmentation devices. In option 1, instantaneous pitch or roll rate is calculated by having the difference between the current rate and the desired rate exponentially decrease to zero as a function of time. Maximum rates are derived from aerodynamic lift or load constraints. An equation similar to the above pitch formula exists for instantaneous roll rate. Option 2 also uses desired roll rate to define instantaneous conditions but the damping term is different: A major difference in option 2 is that instead of controlling pitch rate, angle-of attack is modeled as a second-order equation:

$$\ddot{a} + 2\zeta\omega\mathring{a} + \omega^2 a = a^* \qquad [3.2\text{-}3]$$

Many of the parameters in this formula are user defined. ω is input as a function of Mach and altitude, ζ is an aircraft specific constant, $(a^*)_{MAX}$ depends on gross thrust and Mach, and the maximum value of angle-of-attack acceleration (ä) is input versus Mach, altitude, gross thrust, and angle-of-attack. This equation allows aircraft pitch response to be much more closely matched to a complex data set.

Desired angle-of-attack (a*) is related to the desired pitch rate (Ψ^*) through the previously discussed transverse acceleration (A*). If we temporarily ignore any vertical force due to thrust, then the force which generates the acceleration is lift and a function of angle-of-attack:

$$F = m\,A^* = m\,\Psi^*\,V_{a/c} \qquad [3.2\text{-}4]$$

and

$$F = C_{L\alpha}\,\alpha q\,s \qquad [3.2\text{-}5]$$

where $C_{L\alpha}$ is a lift coefficient, q is dynamic pressure, and s is the wing reference area. Equating the two formulas then gives the desired angle-of-attack in terms of the desired pitch rate:

$$\alpha^* = \Psi^*[(m\,V_{a/c}) / (C_{L\alpha}\,q\,s)] \qquad [3.2\text{-}6]$$

3.2.1 Objectives and Procedures

The purpose of this analysis was to identify the differences in flight performance which resulted from an option 1 and option 2 representation of an aircraft and to determine if this difference had a significant impact on scenario outcome. Sample input files provided with the Brawler code define a type 1 aircraft (BAC1) and a type 2 aircraft (BAC1T2). The aerodynamic lift and drag tables for the two aircraft are identical over the same range of angle-of-attack (0.0 to 24 deg), but the type 1 aero tables stop at 25 degrees while type 2 coefficients are defined to a 55 degree post stall condition. Post stall aerodynamic characteristics are only available when a particular type of maneuver is required (Aim_Missile_Type 1), which is prevalent in 1v1 gun encounters. However, the aircraft pitch response differences show up in all the maneuvers. A 1v1 scenario was constructed and exercised for each of the following four aircraft combinations:

Blue = BAC1	Red = BAC1
Blue = BAC1	Red = BAC1T2
Blue = BAC1T2	Red = BAC1
Blue = BAC1T2	Red = BAC1T2

Each aircraft was identically equipped and both pilots had the same value parameters:

4 MSLR	=	4 Long range RF guided missiles
2 MSLI	=	2 Short range IR guided missiles
1 GUN 0	=	1 Gun - Type 0
FCTL1	=	Fire control unit - Type 1
RDR1	=	
IRST1	=	IR search and track unit - Type 1

MWTEST = Missile warning receiver
RWRTEST = Radar warning receiver
NO_VIS_ID = No visual identification
Aggressiveness = 2.0
Mission Value = 5.0
Skill Level = ACE

The scenario was limited to 60 sec with each aircraft initially on the following Route Point input conditions:

Blue X=-15, Y=0, Hdng=90, Alt=30000, Mach=0.9
Red X=0, Y=0, Hdng=270, Alt=30000, Mach=0.9

Fixed scenarios were run using seed number 0000100000 so the maneuvers used and the angular rates achieved could be examined in detail using the IOUT file. Twenty to twenty-five random seed runs were then completed for each case of interest. For the random seeded scenarios data recorded included aircraft killed, missiles fired, and what happened to each missile. After establishing that the initial scenario produced similar kill ratios for sides when they were using the same type aircraft, several adjustments to the “equal” scenario were made to cause both aircraft to make larger maneuvers. These changes included reducing the Red aggressiveness factor from 2.0 to 1.5, increasing the Red Mission Value from 5 to 15, decreasing the Red flight altitude from 30000 to 25000 feet, and offsetting the two flight paths by one nautical mile. IVIEW was frequently used to get a three-dimensional, qualitative evaluation of engagements.

3.2.2 Results

Beyond Visual Range (BVR) Missile Engagements

In the vast majority of the scenarios each aircraft would launch one semi-active radar guided missile (MSLR). If there was a launch failure, a second MSLR was launched about two seconds later. When both missiles failed to kill their target, short range infra-red missiles (MSLI) were launched. Although both aircraft were also armed with guns, they were never used, probably because the 60 second scenario limit was reached first.

Results from the four fixed scenarios definitely showed the T2 aircraft produced higher maximum angular rates, but they were seldom used because of the BVR scenario. Maximum observed rates for each type of airplane are listed in the Table 3.2-1 in degrees /second:

TABLE 3.2-1. Maximum Angular Rates.

	Roll Rate	Pitch Rate	Yaw Rate
Type 1 a/c	179	23.8	22.2
Type 2 a/c	259	40.5	37.5

These BVR engagements were dominated by missile attacks, with very little difference in the number of missiles fired. Blue aircraft launched 88 MSLR and 27 MSLI. Red aircraft launched 86 MSLR and 19 MSLI. The angular rate capability of each aircraft also did not affect how many missiles were launched; as, type 1 (BAC1) aircraft shot 88 MSLR and 24 MSLI, while type 2 (BAC1T2) aircraft shot 86 MSLR and 22 MSLI. Even with the equality of missiles launched, the scenario results favored the blue side regardless of which side had the more capable aircraft, primarily because of large differences in missile failure rates. MSLR results show that red aircraft had a 64% missile failure rate while on 25% of missiles fired by blue aircraft. Kill summaries are shown in Table 3.2.2.

TABLE 3.2-2. Kill Summary for 1v1 Scenarios.

	Blue a/c Killed	Red a/c Killed	Both a/c Killed	None
Red & Blue type 1	12	19	7	4
Red & Blue type 2	3	11	4	2
Red type 2, Blue type 1	2	14	5	2
Red type 1, Blue type 2	5	10	3	3

Aggressiveness and Mission Value

This leaves the most obvious cause for the scenario outcome differences to be the aggressiveness and mission value factors which were weighted in favor of the blue side. To check this possibility the four scenarios were rerun with the two factors equal for both sides. As shown in Table 3.2-3 below the results were approximately equal for all aircraft combinations.

TABLE 3.2-3. Kill Summary for 1v1 Scenarios with Equal Aggressiveness.

	Blue a/c Killed	Red a/c Killed	Both a/c Killed	None
Red & Blue type 1	10	10	3	1
Red & Blue type 2	6	6	10	3
Red type 2, Blue type 1	9	8	6	3
Red type 1, Blue type 2	8	11	6	2

It appears from the above results that the differences in the two aerodynamic algorithms do not significantly effect scenario outcome for BVR engagements.

Short Range Gun Engagements

To accentuate the aircraft differences a number of 1v1, short range encounter geometries were modeled with each aircraft armed only with guns. Pilot characteristics and aircraft equipment were the same for all aircraft, so the only differences were the type 1 and type 2 aerodynamics. At the start of an engagement both aircraft were in level flight at Mach 0.9. All the encounters were repeated with type 1 aircraft for both sides to provide a baseline for evaluating differences. Maximum time for all scenarios was 80 seconds.

Twenty random seed number encounters were run for all but the head to head geometry; with 40 runs completed for that case. Scenario results are shown in Table 3.2-4.

TABLE 3.2-4. Summary of Short Range Gun Brawls.

Starting Geometry	Aircraft Type	Number Of A/C Killed			
		Blue	Red	Both	None
1. Red Crossing 2 NM ahead of Blue, with Red @ 25K and Blue @ 30K	RED T1, BLUE T2	9	2	1	8
	RED T1, BLUE T1	0	11	0	9
2. Red Crossing 1 NM ahead of Blue, with Red @ 25K and Blue @ 30K	RED T1, BLUE T2	6	3	5	6
	RED T1, BLUE T1	3	14	0	3

TABLE 3.2-4. Summary of Short Range Gun Brawls. (Contd.)

Starting Geometry	Aircraft Type	Number Of A/C Killed			
		Blue	Red	Both	None
3. Blue Crossing 1 NM ahead of Red, with Red @ 30K and Blue @ 25K	RED T1, BLUE T2	19	0	0	1
	RED T1, BLUE T1	19	0	0	1
4. EA at 25K ft. & 1 NM From Crossing At Right Angles	RED T1, BLUE T2	14	4	0	2
	RED T1, BLUE T1	14	4	2	0
5. EA at 25K ft. & 2 NM From Crossing At Right Angles	RED T1, BLUE T2	10	3	6	1
	RED T1, BLUE T1	5	5	10	0
6. EA at 25K ft, 2 NM Initial Separation Head to Head	RED T1, BLUE T2	14	12	10	4
	RED T1, BLUE T1	11	16	10	3
7. EA at 25K ft, Blue 0.5 NM Behind Red	RED T1, BLUE T2	1	18	0	1
	RED T1, BLUE T1	0	17	0	3
8. EA at 25K ft, Red 0.5 NM Behind Blue	RED T1, BLUE T2	20	0	0	0
	RED T1, BLUE T1	16	1	0	3
9. EA at 25K ft, Flying Side by Side, 0.5 NM Apart	RED T1, BLUE T2	12	3	0	5
	RED T1, BLUE T1	7	8	0	5
10. Blue @ 30K, Red @ 25K Blue Directly Above Red	RED T1, BLUE T2	18	0	0	2
	RED T1, BLUE T1	20	0	0	0
11. Red @ 30K, Blue @ 25K Red Directly Above Blue	RED T1, BLUE T2	14	3	0	3
	RED T1, BLUE T1	0	18	0	2

As shown in Table 3.2-4, the blue losses are often higher when a type 2 aircraft is used, although in some scenarios one aircraft has enough tactical advantage so a/c type makes no significant difference in the outcome.

3.2.3 Conclusions

The type 2 aircraft demonstrated an ability to reach larger angular rates than the type 1 aircraft, and is capable of maneuvering to much higher angles of attack. However, this angle of attack capability is seldom used and resulted in no discernible advantage in this study. The commanded angle of attack equation set used for the type 2 aircraft allows a higher fidelity modeling of aircraft motion, but it too failed to produce a tactical advantage. It was suggested that the more accurate aircraft representation provided by algorithm 2 serves to correct overestimates in performance by the simpler model. This seems contrary to the angular rate differences that were observed. Whatever the reason, significant differences in scenario outcome can occur when an aircraft is represented by the two algorithms; so, selection of the algorithm used to represent a new aircraft must be carefully evaluated.

When this conclusion was relayed to the model developer, they were not surprised due to what was described as optimistic performance of the Type 1 aircraft model supplied with the code. To illustrate the tactical advantage afforded by a Type 2 aircraft with a post-stall flight capability, they provided the following two figures that were derived from data collected during two engagements.

Figure 3.2-1 shows differences in off boresight angle (Delta OBA) as a function of time for a close-in gun brawl between two Type 1 aircraft. From the perspective of the Blue aircraft, positive OBA values are good because they indicate that the Red aircraft is in front of the Blue aircraft and conversely, negative OBA values are bad. As shown in the figure, the Red aircraft enjoys a tactical advantage due to geometry (being behind the Blue aircraft) for most of the engagement.

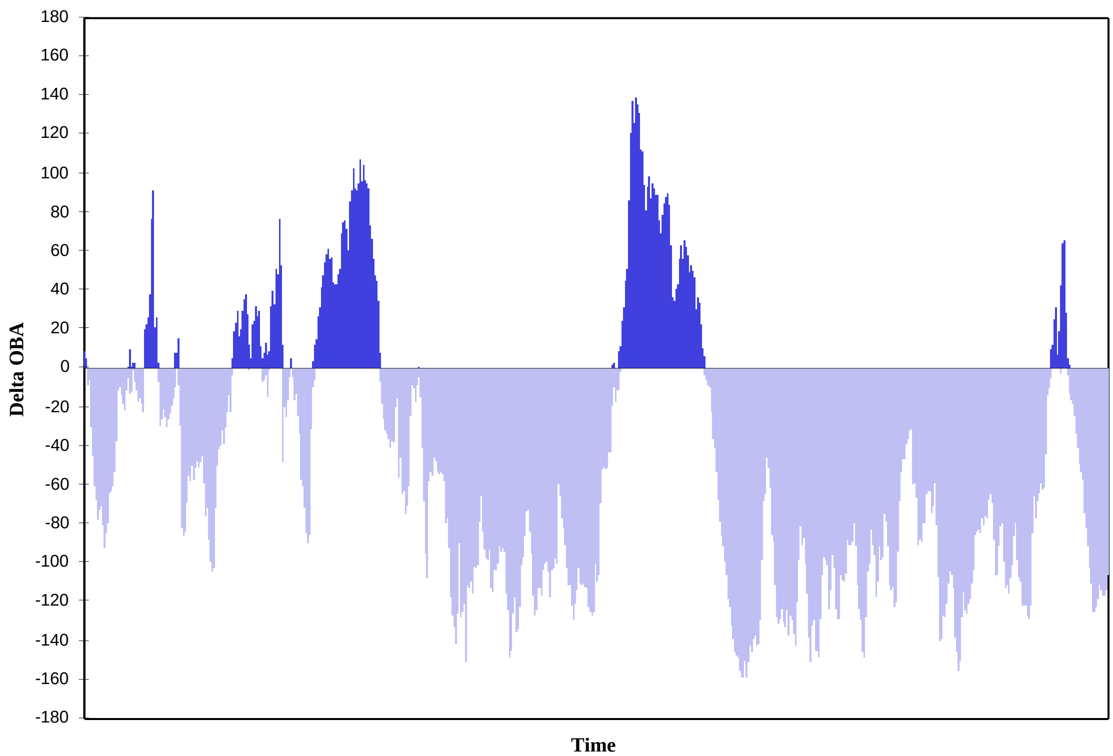

FIGURE 3.2-1. Relative Position Differences Without Post-stall Capability.

When the Blue aircraft has a high angle-of-attack, post-stall (vectored thrust) capability, the OBA values shown in Figure 3.2-2 reveal an ability to reverse the tactical advantage as well as maintain it for a longer period of time. Obviously, the ability to fly slower, at high angles of attack affords a significant advantage in this case. Unfortunately, such engagements are not envisioned to be commonplace in the air-to-air combat environment of the future, so the impact illustrated here will not be realized in the BVR arena. Other benefits, however, such as the ability to aim missiles prior to launch may still make vectored thrust designs worth the additional cost and loss of thrust realized when employing them.

No indications of problems with either model type were noted during this analysis as both are data driven and algorithms are standard. Validation of both the Type 1 and Type 2 aero models should be straightforward given the amount of flight test data collected for many types of aircraft over the years, but would also be daunting unless confined to a few specific airframes. Data sources at the NASA Dryden Flight Test Center should be exploited where test data on experimental aircraft with thrust vectoring nozzles is also available.

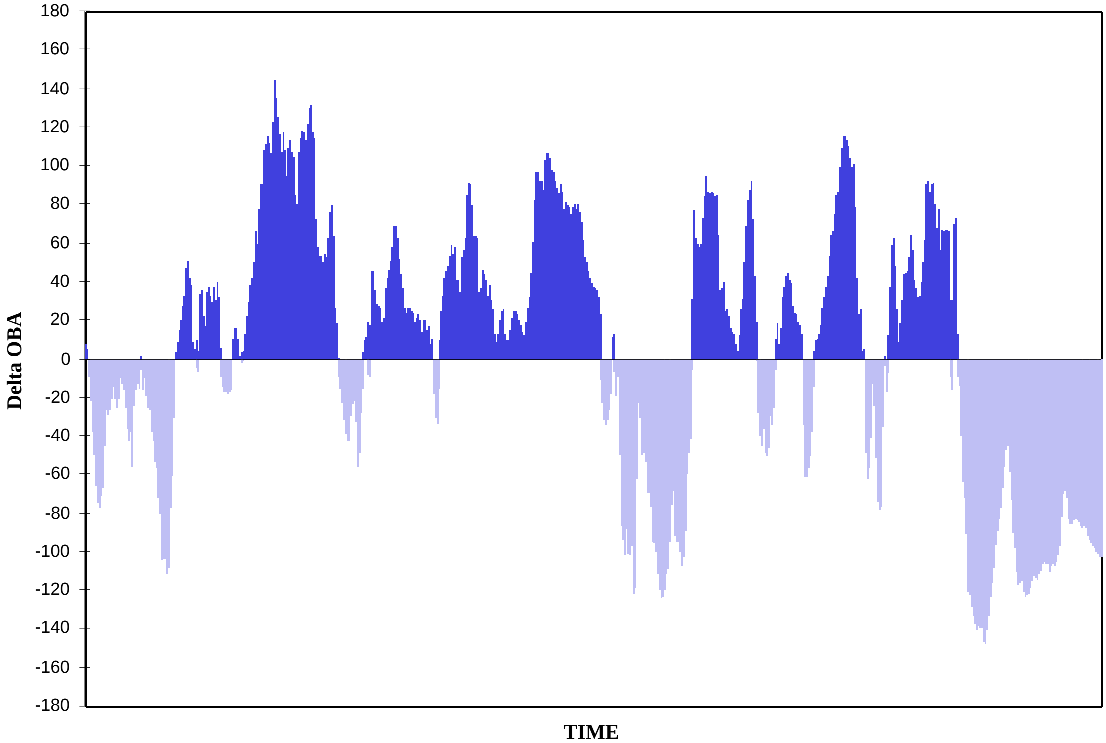

FIGURE 3.2-2. Relative Position Differences With Post-stall Capability.